

THE DESIGN OF PEST STABLE CORN AGROECOSYSTEMS
BASED ON THE MANIPULATION OF INSECT POPULATIONS
THROUGH WEED MANAGEMENT

BY

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To Grisell, Naraya, Joshua and Padre Ricardo
whose love and strength made this work possible,
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Populations of insect pests and associated predaceous arthropods were sampled by direct observations and other relative methods on simple and diverse corn habitats at two sites in North Florida during 1978 and 1979. Through various cultural manipulations (direct sowing, differential fertilization, early plowing, etc.) certain weed communities were selectively established in alternate rows within corn plots.

Fall armyworm (Spodoptera frugiperda J.E. Smith) incidence was consistently higher in the weed-free habitats than in the corn habitats containing natural weed complexes or selected weed associations. Corn earworm (Heliothis zea Boddie) damage was similar in all weed-free and weedy treatments suggesting that this insect is not greatly affected by weed diversity. Only the diversification of corn with a strip of soybean significantly reduced corn earworm damage.

In one of the sites distance between plots was deliberately reduced. Because predators moved freely from one habitat to the other, such movements made treatments more similar in their predator fauna and it was hard to establish real population differences. Large distances between plots minimized this complication and population densities and diversity of common foliage insect predators were greater in the weed diversified corn systems than in the weed-free plots. Trophic relationships in the weedy habitats were very complex compared to food webs in monocultures.

Differences in the abundance of ground predators between plots could not be attributed to weed diversity. Predator pressure was monitored using Spodoptera eggs as artificial prey. The numbers of fall armyworm eggs taken were not shown to be related to numbers of predators present nor to the type and density of the vegetation. Corn systems mulched with rye straw had the lowest infestation of fall armyworm and the highest numbers of predaceous earwigs.

The mean number of predator species and individuals was higher at the site where corn plots were surrounded by complex vegetation than at the site surrounded by annual crops, probably because diverse adjacent areas provided refuge to predators, thus acting as colonization sources.

Corn-weed mixtures confer advantages in pest management and can be agronomically acceptable, although corn yields were generally lower in the weed diversified corn plots than in the weed-free plots. These systems can be designed to be self-operating without much technological inputs. Such an agroecosystem has obvious implications in an era of energy crisis and environmental concern.

INTRODUCTION

The main motivation for this study is the concern that despite numerous reviews and discussions concerning ecological theory and pest management (e.g., Southwood and Way 1970, Price and Waldbauer 1975, Levins and Wilson 1979), questions central to ecology like the relationships among diversity, complexity and stability of organisms in ecosystems have had no major impact on economic entomology. In this study, stability is defined as restricted fluctuations in pest population density through time and diversity as a measure of richness of species in a habitat (Murdoch 1975). Little work has been done on the design of crop systems based on ecological principles. Only a few attempts have been made to modify monocultural systems in the direction of diversity for the purpose of enhancing ecological features vital for successful pest management (Litsinger and Moody 1976, Perrin 1977).

Most researchers concerned with the ecological basis for the management of insect populations attribute outbreaks of insect pests in agriculture to the extensive use of large crop monocultures (Southwood and Way 1970, Price and Waldbauer 1975, Atsatt and O'Dowd 1976, Pimentel and Goodman 1978). Exposed fields and concentrations of a single crop species open myriad possibilities for pest infestations (Browning 1975). Pure crop stands provide concentrated resources and uniform physical conditions that directly influence members of the crop

fauna (Root 1973). The abundance and effectiveness of general predators are reduced because these simplified environments do not provide adequate alternate sources of food, shelter, breeding sites, and other environmental factors (Hagen et al. 1976). Herbivorous insect pests are more likely to colonize and remain longer on crop hosts that are concentrated because usually the pests' entire life requirements are met in these simple environments (Root 1973). As a result, the abundance of specialized pests attain economically unacceptable levels.

Many crop plants, like their wild relatives, fare better in species diverse, structurally complex communities (Wilken 1977). Crops grown in floristically diverse habitats suffer a lower herbivore load than conspecifics grown in monocultures. Many studies have shown that reducing crop stand purity by interplanting different crop species greatly reduces the density of herbivorous pests (Marcovitch 1935, Stern 1969, DeLoach 1970, Tahvanainen and Root 1972, Raros 1973, Dempster and Coaker 1974, van Emden and Williams 1974, Litsinger and Moody 1976, Perrin 1977, Altieri et al. 1978, Perrin and Phillips 1978, Risch 1979). Outbreaks of certain types of crop pests are more likely to occur in weed-free fields than in weed diversified crop systems (Pimentel 1961, Adams and Drew 1965, Dempster 1969, Flaherty 1969, Root 1973, Smith 1976a, Altieri et al. 1977). Crop fields with a dense weed cover and high diversity usually have greater numbers of predaceous arthropods than do weed-free fields (Pimentel 1961, Dempster 1969, Flaherty 1969, Pollard 1971, Root 1973, Smith 1976b, Speight and Lawton 1976). Ground beetles (Dempster 1969, Speight and Lawton 1976, Thiele 1977), syrphids (Pollard 1971, Smith 1976b) and lady beetles (Bombosch

1966, Perrin 1975) have been reported to be greatly abundant in weed diversified systems. The presence of certain weeds within crop habitats offers many important requisites for natural enemies such as nectar and pollen sources, alternate prey and hosts and microhabitats that may not be available in a monoculture (Altieri and Whitcomb 1979).

Based on experimental results and on theoretical considerations which imply that diversity of species and habitat complexity confer stability to the insect community (Pimentel 1961, van Emden and Williams 1974, Murdoch 1975), some researchers have envisaged the maintenance of specific weed associations in crop areas to provide subsidiary food for entomophagous insects and thus, improve biological control of certain pest species (van den Bosch and Telford 1964). Practical implementation of this approach remains disappointingly low, however.

The present study describes some ways in which corn agroecosystems could be designed to reduce the severity of insect pest problems. Discussed herein are some of the changes in abundance that target pests and associated predators undergo when certain weed associations are selectively allowed to grow in corn fields to provide additional safeguards against pest insects.

LITERATURE REVIEW

Some Limitations for the Development of Sound Pest Management Systems

The efficient integration of several methods of pest control to suppress a complex of pests while achieving maximum yield and quality on one hand and minimum damage to the environment on the other, have been major goals of integrated pest management (IPM) (Rabb and Guthrie 1970, Metcalf and Luckman 1975). This desired balance has seldom been attained, however. There are several reasons:

1. Contemporary pest management practice still has too narrow an ecological knowledge base. Overemphasis on yield or market quality almost invariably means shattering of the crop community homeostasis (DeLoach 1970). Seldom can maximum stability and maximum productivity be achieved simultaneously in the same ecosystem (Turnbull 1969). Increasing agricultural production will always involve risk of serious degradation of at least some agro-ecosystems (Loucks 1977). For this reason, stabilization of yield rather than maximization of yield should be a major goal of IPM.
2. The explosive expansion of the pesticide industry has inflicted strong socioeconomic and philosophical obstacles to the development of sound ecological pest management strategies. The present agricultural epoch, clearly dominated by the petrochemical industry, envisions food cultivation as a business enterprise to be operated strictly for the

purpose of generating profit in a market economy (Bookchin 1976, van den Bosch 1978). Integrated pest management should be part of a philosophy that views agriculture as the activity of a society whose historic role is to maintain, within ecological limits, productive land in order to sustain present and future generations of people.

3. Nearly all research in pest management is highly reductionist, parochial and discipline-oriented. Few articles with truly holistic approaches have emerged in the trade journals (Potts and Vickerman 1974). A common erroneous pattern of many pest management systems is the combination of various cultural and biological methods of insect control while simultaneously recommending chemicals for the control of weeds and diseases. These programs can lead to intensification of pest problems. For example, 2,4-D is a herbicide commonly used in corn for the post emergence control of broadleaf weeds. When corn plots were treated with a regular dose of 0.55 kg, 2,4-D ha⁻¹, aphid numbers and corn borer infestations increased significantly (Oka and Pimentel 1974). Similarly, corn plants exposed to 2,4-D were significantly more susceptible to corn smut disease and to southern corn leaf blight (Oka and Pimentel 1974). Furthermore, sprays of 2,4-D at normally used rates caused up to 50% mortality of the larvae stages of coccinellids (Adams and Drew 1965). Part of this anti-holistic approach to pest management resides in the lack of trained "generalists" who understand the principles of managing resources as a part of a total interacting environmental system (Pimentel 1970).

Ecological Theory and Pest Management

The ecological basis of pest management has been the topic of many review and journal articles during the past decade (Southwood and Way 1970, Price and Waldbauer 1975, Pimentel and Goodman 1978, Levins and Wilson 1979). Most approaches contrast the structure and function of agroecosystems and natural, undisturbed ecosystems (Southwood and Way 1970, Price and Waldbauer 1975, Rabb et al. 1976, Pimentel and Goodman 1978). Browning (1975) has advised the study of natural ecosystems from which knowledge can be gained that is readily applicable to agroecosystems. According to Price and Waldbauer (1975), agricultural ecosystems can be viewed in terms of two central concepts of ecology— island biogeographical theory (Price 1976) and succession of communities. Most ecologists agree that any pest management approach should try to develop an agroecosystem that emulates later stages of succession (i.e., mature communities) as much as possible, for this is how stability can be achieved (Root 1973). By adding selective diversity to crop systems, it is hoped to capture for agroecosystems some of the stability properties of natural communities (Murdoch 1975). The concept that increased diversity leads to increased stability has been challenged on theoretical grounds (van Emden and Williams 1974) but not by reliable studies in agricultural communities.

For many researchers, the biogeographic region rather than the single homogeneous field is the appropriate unit for pest management research (Levins and Wilson 1979). An agroecosystem should be conceived as an area large enough to include those uncultivated areas which influence crops through intercommunity interchanges of organisms and materials (Rabb 1978). Excellent studies on the role of uncultivated

land and crop field borders in the biology of crop pests and beneficial insects have been made (Dambach 1948, Piemeisel 1951, van Emden 1965, Pollard 1971, Hodek 1973, Thiele 1977). However, little is known yet of the influence of adjacent habitats on pest incidence in cultivated fields.

Dynamics of Insect Populations in Complex Crop Communities

The predisposition of insect outbreaks to occur in monocultures is well known (Pimentel 1961, Browning 1975). Studies of multiple cropping systems have shown that populations of herbivorous pests reach higher densities on crop plants grown in monocultural stands than on plants grown associated with other plant species (Litsinger and Moody 1976, Perrin 1977, Altieri et al. 1978, Perrin and Phillips 1978) (See Table 1 for additional examples). These patterns can be explained on the basis of the following hypotheses:

1. Resource concentration: insect populations can be directly influenced by the concentration or spatial dispersion of their food plants. Many herbivores, particularly specialists, are more likely to find and remain on hosts that are growing in dense or nearly pure stands (Root 1973).

2. Associational resistance: ecosystems in which plant species are intermingled possess an associational resistance to herbivores in addition to the resistance of individual plant species (Root 1975). Interplanting of host plants can drastically decrease colonization efficiency and subsequent population density of crop pests (Tahvanainen and Root 1972). In addition to their taxonomic diversity, polycultures

Table 1. Selected examples of multiple cropping systems that effectively prevent insect pest outbreaks (Altieri et al. 1978).

Multiple cropping system	Pest(s) regulated	Factor(s) involved	References
Cotton intercropped with forage sorghum	Boll weevil (<i>Anthonomus grandis</i>)	Population increase of parasitoid wasps (<i>Eurytoma</i> sp.)	Imreovitch (1935)
Peaches intercropped with strawberries	Strawberry leafroller (<i>Amorbia caryocarpae</i>), European spruce sawfly (<i>Pristiphora vitana</i>), and European spruce sawfly (<i>Grapholita ulmella</i>)	Population increase of parasitoid (<i>Microgaster ancyloides</i>), <i>Microgaster</i> sp., and <i>Microgaster</i> sp.	Nareovitch (1935)
Strip cropping of cotton and alfalfa	Plant bugs (<i>Lycus hesperus</i> and <i>L. alinus</i>)	Prevention of emigration and synchrony in the refugia between pests and natural enemies.	van den Bosch and Stern (1969)
Strip cropping of cotton and alfalfa on one side and maize and soybean on the other	Corn earworm (<i>Heliothis zea</i>) and cabbage looper (<i>Trichoplusia ni</i>)	Increased abundance of predators	DeJongh (1970)
Intercropping cotton with sorghum or maize	Corn earworm	Increased abundance of predators due to an increase of alternate prey	Fye (1972), Burleigh et al. (1973)
Maize intercropped with amaranth	Proctosyllina nigra and fall armyworm (<i>Spodoptera frugiperda</i>)	Not reported	Cuevara (1962)
Tomato and tobacco intercropped with cabbage	Flea beetles (<i>Phyllotreta cruciferae</i>)	Feeding inhibition by odors from nonhost plants	Telavanninen and Root (1972)
Tomato intercropped with cabbage	Diamondback moth (<i>Plutella maculipennis</i>)	Chemical repellency or masking	Rena (1973)
Tomato intercropped with maize	Corn borer (<i>Ostrinia furnacalis</i>)	Abundance of spiders (<i>Lycosa</i> sp.)	Berco (1973)
Tomato intercropped with cotton	Flea beetles (<i>Pedagium</i> sp.)	Chemical repellency	Liesinger and Moody (1976)
Sesame intercropped with cotton	<i>Heliothis</i> spp.	Increase of beneficial insects and trap cropping	Laster and Purr (1972)

Table 1 - continued

Cabbage intercropped with white and red clover	<i>Eristalis brassicae</i> , cabbage aphids, and imported cabbage butterfly (<i>Pieris rabae</i>)	Interference of colonization and increase of ground beetles	Dempster and Cooker (1974)
Sesame intercropped with corn or sorghum	Webworms (<i>Antigontra</i> sp.)	Shading by the taller companion crop	Litsinger and Moody (1975)
Intercropping cowpea and sorghum	Leaf beetle (<i>Ootheca hemispina</i>)	Interference of air currents	Litsinger and Moody (1975)
Cotton intercropped with okra	<i>Podarica</i> sp.	Trap cropping	Litsinger and Moody (1975)
Corn intercropped with sweet potatoes	Leaf beetles (<i>Diabrotica</i> spp.) and leafhoppers (<i>Amalia linaria</i>)	Increase of parasitic wasps	Risch (1979)
Corn intercropped with beans	Leafhoppers (<i>Eumecurus kneri</i>) leaf beetle (<i>Diabrotica balteata</i>) and fall armyworm	Increase of beneficial insects and interference of colonization	Altieri et al. (1978)

have a relatively complex physiognomy, chemical environment and associated patterns of microclimates. This biotic, structural, chemical and microclimatic complexity of mixed vegetation greatly ameliorates the herbivore pressure on the crop systems as a whole (Tahvanainen and Root 1972).

3. Plant apparency: most crops are derived from early successional herbs which largely escaped from herbivores in space and time (Feeny 1976). The effectiveness of natural crop plant defenses is reduced by present agricultural methods. When planted in monocultures, crop plants become more apparent to natural enemies than are their ancestors in nature. The apparency of a crop plant is increased by close association with conspecific individuals (Feeny 1977). Crop plants grown in monoculture are subjected to conditions for which their qualitative chemical and physical defenses are inadequate (Feeny 1976).

4. Natural enemy hypothesis: this hypothesis predicts that there will be a greater abundance and diversity of natural enemies of pest insects in polycultures than in monocultures (Root 1973). Predators tend to have broad diets and habitat requirements so they would be expected to encounter a greater array of alternative prey and microhabitats in a heterogeneous environment (Root 1975). Annual crop monocultures do not provide adequate alternate sources of food (pollen, nectar, prey), shelter, breeding and nesting sites for effective performance of natural enemies (Rabb et al. 1976).

The natural enemy hypothesis has been stated in the following way (Root 1973):

- a. A greater diversity of prey and microhabitats is available within complex environments. As a result, relatively stable

populations of generalized predators can persist in these habitats because they can exploit the wide variety of herbivores which become available at different times or in different microhabitats.

b. Specialized predators are less likely to fluctuate widely because the refuge provided by a complex environment enables their prey to escape widespread annihilation.

c. Diverse habitats offer many important requisites for adult predators, such as nectar and pollen sources, that are not available in a monoculture.

Effects of Crop Habitat Diversity on Natural Enemies

Parasitoids

Several authors have claimed that insect populations are more stable in complex communities because a diverse habitat can maintain an adequate population of the pest and its enemies at critical times (van den Bosch and Telford 1964, DeLoach 1970). For example, parasitoids are more effective in areas where there are abundant wildflowers that provide nectar and pollen (van Emden 1962, Leius 1967, Syme 1975). Also, since the life cycle of many parasitic insects is not synchronized with that of their host's, some parasitoids must rely on alternate hosts to maintain establishment within a community. In many cases, weeds and other natural vegetation in and around crop fields harbor alternate hosts for parasitic insects thus providing seasonal resources to bridge the gaps in the life cycles of parasitoids and crop pests (Peppers and Driggers 1934, van Emden 1965, Douth and Nakata 1973, Syme 1975, Stern et al. 1976, Plakidas 1978). Additional examples can be found in Table 2.

Table 2. Selected examples of cropping systems in which the presence of weeds enhanced the biological control of specific crop pests.

Cropping systems	Weed species	Pest(s) regulated	Factor(s) involved	References
Cabbage	<u>Crataegus</u> sp.	Diamondback moth (<u>Plutella maculipennis</u>)	Provision of alternate hosts for parasitic wasps (<u>Microgaster</u> sp.)	van Emden (1965)
Cotton	Ragweed and <u>Rumex crispus</u>	<u>Heliothis</u> spp.	Increased populations of predators	Smith and Reynolds (1972)
Vineyards	Wild blackberry (<u>Rubus</u> sp.)	Grape leafhopper (<u>Erythroneura elegantula</u>)	Increased of alternate hosts for the parasitic wasp <u>Apanteles</u> sp.	Boutt and Nakata (1973)
Vineyards	Johnsongrass (<u>Sorghum halepense</u>)	Pacific mite (<u>Eotetranychus willamettei</u>)	Buildup of predaceous mites (<u>Metatetranychus occidentalis</u>)	Flaherty (1969)
Beans	Goosegrass (cleansing indigo) and red sprangletop (<u>Leptochloa filiformis</u>)	Leafhoppers (<u>Eumecurus kneri</u>)	Chemical repellency or masking	Altieri et al. (1977)
Collards	Ragweed (<u>Ambrosia artemisi-</u> <u>folia</u>)	Flea beetle (<u>Phyllotreta crucifera</u>)	Chemical repellency or masking	Tohvanainen and Root (1972)
Apple	Natural weed complex	Tent caterpillar (<u>Malacosoma americanum</u>) and eating moth (<u>Carpocapsa pomonella</u>)	Increased activity and abundance of parasitic wasps	Leius (1967)
Vegetable crops	Wild carrot (<u>Daucus carota</u>)	Japanese beetle (<u>Popillia japonica</u>)	Increased activity of the parasitic wasp <u>Tiphia popillivora</u>	King and Holloway (1970)
Apple	Phacelia sp. and <u>Erigeron</u> sp.	San Jose scale (<u>Aspidiotus perniciosus</u>) and aphids	Increased abundance and activity of parasitic wasps (<u>Apanteles mali</u> and <u>Aphidius praeator</u>)	Teichgraber (1958)
Cruciferous crops	Quick flowering mustards	Cabbageworms (<u>Pieris</u> spp.)	Increased activity of parasitic wasps (<u>Microgaster flaviventris</u>)	National Academy of Sciences (1965)

Table 2--continued

Corn	Giant ragweed	European corn borer (<u>Pyrausta nubilalis</u>)	Provision of alternate hosts for the tachinid parasite <u>Lydella dybroskii</u>	Syme (1975)
Cotton	Ragweed	Boll weevil (<u>Anthonomus grandis</u>)	Provision of alternate hosts for the parasite <u>Phytomyza tylosomatina</u>	van den Bosch and Teiford (1964)
Peach	Ragweed	Oriental fruit moth	Provision of alternate hosts for the parasite <u>Microcentrus deileatus</u>	van den Bosch and Teiford (1964)
Alfalfa	Natural blooming weed complex	Alfalfa caterpillar (<u>Colias eurytheme</u>)	Increased activity of the parasitic wasp <u>Microgaster mutatorialis</u>	van den Bosch and Teiford (1964)
Sweet potatoes	Morning glory (<u>Ipomoea tortilis</u>)	Argus tortoise beetle (<u>Chelymorpha casatida</u>)	Provision of alternate hosts for the parasite <u>Phaenocarpa</u> sp.	Carroll (1978)
Sugar cane	<u>Borer</u> (<u>Diurapha viridula</u>) and <u>Diurapha viridula</u>	Crick (1967)	Provision of nectar for the parasite <u>Phaenocarpa</u>	Wolcott (1942)
Yungbeans	Natural weed complex	Beanfly (<u>Ophiomyia phaseoli</u>)	Alteration of colonization background	Litsinger and Woody (1976)
Brussel sprouts	Natural weed complex	Imported cabbage butterfly (<u>Pieris rapae</u>) and aphids (<u>Brevicoryne brassicae</u>)	Alteration of colonization background and increase of predators	Smith (1976a, b)
Sugar cane	Ragwort (<u>Lythrum</u> spp.)	<u>Diurapha viridula</u> and <u>D. viridula</u>	Provision of nectar and pollen for the parasitoid <u>Ichneumon</u> spp.	Myers (1931)

Peterson (1926) observed that uncultivated orchards were less severely attacked by codling moth than thoroughly cultivated orchards. Later, Peppers and Driggers (1934) and Allen and Smith (1958) showed that percentage of fruit moth larval parasitism was always greater in orchards with weeds than in clean cultivated orchards. Similarly, Leius (1967) found that the presence of wild flowers in apple orchards resulted in an 18-fold increase in parasitism of tent caterpillar pupae over non-weedy orchards. Tent caterpillar egg parasitism increased four times, and codling moth larval parasitism increased five times.

Predators

The replacement of natural communities or diversified agriculture with large monocultures has caused general predator fauna impoverishment in certain agricultural areas (van den Bosch and Telford 1964). As far back as 1935, Marcovitch envisaged the diversification of cropping systems as a means of increasing the efficacy of naturally occurring predator populations. Later, Root (1973) proposed the "natural enemy hypothesis" which states that predators are more effective and abundant in diverse habitats than in simple ones. Results from several experiments back up this hypothesis.

In the Solomon Islands, O'Connor (1950) recommended a cover crop be used in coconut groves to improve the biological control of coreid pests by the ant Oecophylla smaragdina subnitida Emery. In Ghana, coconut gives light shade to cocoa and supports without apparent crop loss, high populations of Oecophylla longinoda, keeping the latter free from cocoa capsids (Leston 1973).

In the Canete Valley of Peru growing corn in conjunction with cotton was ideal for the reproduction of predators that contributed to the biological control of cotton leaf rollers Argyrotaenia sphaleropa Meyrick and Platynota sp., and the bollworm Heliothis virescens (F.) (Wille 1952, Beingolea 1957). Growing alfalfa strips within cotton fields in California significantly increased numbers of predators early in the season; these beneficials moved back and forth between the alfalfa and the cotton (Stern 1969).

Intercropping systems of cotton with corn or sorghum presented higher numbers of predaceous arthropods (primarily lady beetles and lacewings) than cotton monocultural systems (DeLoach 1970, Fye 1972, Burleigh et al. 1973, Stern et al. 1976). Similarly, cotton-sesame interplantings had high populations of beneficial insects (Laster and Furr 1972). Intercropping of corn and peanuts (Arachis hypogaea L.) decreases the incidence of the corn borer [Ostrinia furnacalis (Guenee)] probably because these habitats encourage the abundance of Lycosa sp. spiders (Litsinger and Moody 1976). In Costa Rica, increasing resource diversity by intercropping corn and sweet potatoes enhances the relative abundance and diversity of predators (Risch 1979). Similarly, in tropical Colombia, corn-bean polycultures had higher numbers of predaceous Hemiptera and Dolichopodidae than corresponding monocultures (Altieri et al. 1978). Larger numbers of ground beetles (i.e., Harpalus rufipes) in mixed plots of cabbage and clover reduced survival of Pieris caterpillars (Dempster and Coaker 1974).

Populations of many predator species seem to depend on general abundance of hibernating sites and alternative hosts as well as flowers in hedges and other habitats in the area, not just around the immediate

edge of the field (Pollard 1971). The management of habitats surrounding crops could augment regional populations or predators if widely practiced (Perrin 1975). Populations of arthropod predators were higher in diverse permanent habitats than in simple habitats (Pollard 1971, Fuchs and Harding 1976).

The importance to pest control of the presence of uncultivated habitats adjacent to crops is inconclusive. More is known about the influence of diversifying the crop habitat itself on insect populations.

The presence of certain weeds within a crop can greatly influence the balance of members of the crop fauna. Reduced incidence of crop pests in weedy crop systems compared to weed-free monocultures has been demonstrated by Pimentel (1961), Dempster (1969), Tahvanainen and Root (1972), Root (1973), Smith (1976b), and Altieri et al. (1977).

In many cases, the reduced pest numbers have been the result of an increase of predator populations (Altieri and Whitcomb 1979). Coccinellids, syrphids, Aphidoletes sp. and other predators were more abundant and preyed more actively on aphids in cole plants grown among diverse meadow vegetation than in cole monocultures (Pimentel 1961, Root 1973). Ground beetles (Harpalus rufipes, Feronia melanaria and others) and a harvest spider (Phalangium opilio) were more abundant in weedy cabbage crops than in weed-free monocultures (Dempster 1969). In England, Smith (1976a) found that oviposition of certain syrphid predators and abundance of the anthocorid Anthocoris nemorum were increased in brussel sprouts with a weedy background. Populations of coccinellids were higher in weedy oat fields in New Brunswick than in weed-free monocultures (Adams and Drew 1965). Similarly, areas of dense weed cover in English cereal fields had more predatory ground

beetles (Carabidae and Staphylinidae) than did weed-free areas (Speight and Lawson 1976).

Weed as Sources of Predators

Perrin (1975) and Altieri and Whitcomb (1979) have emphasized the role of certain weeds as sources of alternate prey of important predators of crop pests. To improve survival and reproduction of predators within an agroecosystem, it is often desirable to have subeconomic, fluctuating populations of alternate prey permanently present in the crops (van den Bosch and Telford 1964). Specific examples of weeds that provide alternate food resources for predaceous arthropods are listed in Table 3. If widely encouraged, these plants show potential in insuring a standing population of specific predators in areas where these interactions occur consistently.

Table 3. Selected examples of weeds that provide alternate prey for general predators.

Weed	Alternate prey	Predators	References
<u>Urtica dioica</u>	<u>Microlophium carnosum</u>	Coccinellidae and Syrphidae	Perrin (1975)
<u>Fastinaca</u> sp. and <u>Achillea</u> sp.	Aphids	Coccinellidae and predaceous Hymenoptera	Bombosch (1966)
<u>Solanum carolinense</u>	<u>Leptinotarsa decemlineata</u>	<u>Lebia grandis</u>	Hemenway and Whitcomb (1967)
<u>Ananthurus</u> sp.	<u>Disonychia glabrata</u>	<u>Lebia anella</u>	"
<u>Oenothera lacinata</u> and <u>O. biennis</u>	<u>Altica</u> sp.	<u>Lebia viridis</u>	"
<u>Heterotheca subaxillaris</u>	<u>Zygogramma heterothecae</u>	<u>Lebia atriventris</u> , <u>Perillus bioculatus</u> , <u>Touretia viridans</u> and other spiders	Altieri and Whitcomb (1979)
<u>Chenopodium ambrosioides</u>	<u>Zygogramma suturalis</u> , aphids and Cicadellidae	<u>Callida decorata</u> , <u>Perillus bioculatus</u> , <u>Hippodamia convergens</u> , and other Coccinellidae; <u>Lebia viridis</u> ; <u>Tetragnatha</u> sp. and other spiders	Altieri and Whitcomb (1979)
<u>Solidago altissima</u>	<u>Uroleucon</u> spp.	<u>H. convergens</u> and other Coccinellidae, <u>Chrysopa</u> spp., <u>Pedabrus</u> sp. and <u>Chauliognathus</u> spp.; <u>Zelus cervicalis</u> and other Reduviidae, <u>Condylonyx</u> sp., <u>Psecetta vittatus</u> and other spiders, <u>Toxomerus</u> sp. and other Syrphidae	Altieri and Whitcomb (1979)
<u>Sorghum halepense</u>	Non target mites	<u>Metascius occidentalis</u>	Fisherty (1969)
<u>Cirsium arvense</u>	<u>Altica eridanthorum</u>	<u>Lebia viridis</u> , <u>Harpalus pennsylvanicus</u>	Schauber et al. (1975)

MATERIALS AND METHODS

The effects of weed diversity on the dynamics of corn insect pests and associated predators were tested in experiments at two sites.

Tall Timbers Site

This experiment was conducted in a 5 ha field located at Tall Timbers Research Station in northern Leon County, Florida. On April 5, 1978, the field was divided into eighteen 100 m² plots (10 rows, each 10 m long) and planted with corn (Zea mays L., c.v. 'Kernel Greenwood Hybrid'). The distance between rows was 0.9 m (36 in). Plots were separated by 50 m to reduce variability due to immigration and emigration of arthropods. The soil between the plots was kept free of vegetation by frequent harrowing. Fertilizer (5-10-15) was applied to the corn plots at a rate of 436.4 kg/ha (400 lb/a).

There were six treatments, each replicated three times:

1. Corn monoculture (weed-free).
2. Corn + weed mixture A. This mixture consisted of seeds of Solidago altissima L. (golden rod), Amaranthus sp. (pigweed), and Heterotheca subaxillaris (Lam.) (camphorweed), sowed when the corn was planted.
3. Corn + mixture B. This mixture consisted of seeds of Ambrosia artemisiifolia L. (ragweed), Chenopodium ambrosioides L. (mexican tea), and Daucus carota L. (wild carrot) also sowed when the corn was planted.

4. Corn + natural weed complex, highly fertilized. The rows in which the native weeds were allowed to grow were fertilized with 5-10-15 at a rate of 872.8 kg/ha (800 lb/a).

5. Corn + natural weed complex, regularly fertilized at the usual rate of 436.4 kg/ha.

6. Corn + natural weed complex determined by an early plowing (the rows in which the weeds were allowed to grow were previously plowed by the end of December 1977 and since then left undisturbed).

In all treatment plots, native weeds were allowed to grow freely in the two middle rows and in the rows before the last on each side of the plot. The plots in which weed mixtures were sowed had a background of native weeds. Each plot had six rows of corn and four rows of weeds. The area between the six rows of corn was kept weed-free by cultivation and hoeing.

Pest incidence on corn by lepidopterous larvae (mainly Spodoptera frugiperda J.E. Smith) was estimated by counting the number of plants with damaged whorls in each plot. Thirty corn plants were randomly selected every 7 days in each plot and their degree of damage was evaluated visually. Similarly, numbers of predaceous arthropods on corn were estimated by careful visual examination of the above-ground parts of 30 corn plants at each plot every 7 days. The number and type of predator species on each plant was recorded and, when possible, prey items. Populations of predaceous arthropods present on the weeds in the plots were evaluated by taking 20 sweepnet samples along the two middle weedy rows of each plot. Sweepnet contents were analyzed immediately by opening the sweepnet and counting the number of predator species crawling along the bag.

Predator pressure in the various plots was assessed using fresh 2-day-old Spodoptera eggs. One hundred eggs were attached to pieces of white paper towel on the rough side. These pieces were stapled to white paper cards and then placed in the field (two cards per plot) pinned to corn leaves at the center of each plot. Egg cards were left for 24 hours, after which time they were collected and the numbers of eggs attacked and removed were counted with the aid of a stereo microscope. Fresh cards were placed again in the plots. This procedure was repeated four times. In some instances the arthropods involved in egg removal were specified by direct observation.

Weed density and species composition in each plot were estimated on three occasions by using a 0.5 m^2 quadrat. Each quadrat was randomly thrown and examined twice in the two middle weedy rows of each plot. Numbers of plant and species enclosed in each quadrat were recorded.

Relative abundance and species composition of soil arthropods were monitored with pitfall traps filled with killing fluid (approx. 50 ml of 95% alcohol). One trap per plot was used and was left in the ground for 14 days. After this time, traps were removed, and the contents were sorted to species and counted in the laboratory. This procedure was repeated five times during the experiment.

The relative abundance and species composition of flying predaceous insects (mainly Dolichopodidae and some wasps) were estimated by placing a yellow pan in the middle of each plot. Each pan was filled with water and a few drops of detergent were added to ensure that insects caught sank to the bottom of the pans. The pans were left in the field for 3 days. After this time, the pans were emptied and the contents

sorted according to species and counted in the field. This procedure was repeated five times during the experiment.

Green Acres Site

This experiment was conducted in a 1 ha field at the University of Florida, Green Acres Farm about 20 km west of Gainesville, Florida. The entire field was planted solidly to corn ('Coker 71') on March 27, 1979, and afterwards divided into 18 randomly distributed plots of 100 m^2 each (10 rows, each 10 m long). The distance between rows was 0.9 m (36 in.). Plots were separated by 8 m; however, corn was allowed to grow around the plots. Those plants growing in the vicinity of the plot edges were cut back regularly with a machete to a height of 20 cm. Fertilizer (6-12-18) was applied to the corn plots at a rate of 436.4 kg/ha (400 lb/a).

There were six treatments, each replicated three times:

1. Corn monoculture (weed-free).
2. Corn + weed mixture A. This mixture consisted of seeds of Amaranthus retroflexus L. (red pigweed), Xanthium pennsylvanicum Wallroth (cocklebur), Oenothera biennis L. (evening primrose), and Chenopodium ambrosioides L. (mexican tea), which were sowed simultaneously with the corn.
3. Corn + weed mixture B. This mixture consisted of seeds of Taraxacum officinale Wiggers (dandelion), Heterotheca subaxillaris (Lam.) (camphorweed), Solidago altissima L. (goldenrod), and Bidens pilosa L. (beggartick) which were simultaneously sowed with the corn.
4. Corn + soybean.
5. Corn + natural weed complex.

6. Corn + rye straw mulch.

In treatments 2, 3, and 5 native and sowed weeds were allowed to grow freely between the two central corn rows of each plot. Selected weeds were also grown in pots in the greenhouse and later transplanted to the plots to assure a high population of desired weeds in each treatment. In treatment 4, two rows of soybeans were planted between the two central corn rows of each plot. The remaining area of the plots was kept weed-free by cultivation and hoeing.

The incidence of Spodoptera frugiperda J.E. Smith, predator population and predator pressure were estimated by the same methods used at the Tall Timbers site.

Two pitfall traps were placed four times in all treatments to estimate relative abundance of ground beetles and earwigs. No yellow pans were used in this experiment.

Weed densities and species composition were estimated using a thin (2 mm diameter) metal rod which was let down vertically to the ground in 20 random places per plot, and all weed leaves (and soybean leaves in the case of treatment 4) touched by the vertical middle were recorded. When totalled up for all the intersections, this gave an estimate of the percent cover and leaf area index of each weed species and the total plant community (Wilson 1963).

In both experiments, corn yields were estimated by weighing corn ears harvested from an area of 29 m^2 in the center of each plot, once the ears reached a moisture level of 15%.

RESULTS AND DISCUSSION

Nature of the Weed Communities

Weeds of Tall Timbers Research Station

Weed communities within all corn plots were mainly composed of associations of cocklebur, sicklepod (Cassia obtusifolia L.), Florida purslane (Richardia scabra L.) and grass species. Because of dormancy problems the weed seeds sowed in treatments 2 and 3 (weed mixture A and B) failed to germinate adequately. Consequently, populations of goldenrod, pigweed, camphorweed, wild carrot and mexicantea remained at low densities during the whole study. However, the mere presence of these weeds in the plots contributed to the background diversity of each treatment making the weed communities different from each other. The density of individual species within each weed community varied considerably among treatment plots (Table 4). Treatments 2 and 4 had the highest number of plants per 0.5 m^2 and were dominated by grass species such as Panicum sp. and Andropogon sp. Both Cassia and grasses were stimulated by high fertilization. Richardia was particularly abundant in treatment 2. The plot previously plowed in December had a unique background of perennial weeds (e.g., Rubus sp., Phytolaca sp. etc.) and annuals such as rattlebox (Crotalaria spectabilis Roth) and cypress vine (Ipomoea quamoclit L.).

Table 4. Densities and species numbers of weed communities within corn fields at Tall Timbers Research Station in north Florida (1978).

Treatment	Weed community	Mean density of species per 0.5 m ²			Mean number of weed species	Mean number of plants per 0.5 m ² in the weed community \pm std. deviation (n=9)
		<u>Xanthium</u>	<u>Cassia</u>	<u>Richardia</u>	<u>Grasses*</u>	
2	Weed mixture A	2.0	17.0	77.0	56.0	11 82.5ab** \pm 12.6
3	Weed mixture B	3.0	36.0	58.0	23.0	7 66.8b \pm 7.2
4	Natural weed complex highly fertilized	1.0	70.0	38.0	54.0	8 88.8a \pm 18.1
5	Natural weed complex regularly fertilized	4.0	53.0	74.0	7.0	9 75.4ab \pm 22.2
6	Natural weed complex determined by December plowing	0.0	2.0	24.0	34.0	10 32.2c \pm 12.9

* Panicum sp., Andropogon sp. and Cyperus sp.

** Means followed by the same letter, on any given column, are not significantly different according to Duncan's multiple range test ($p = 0.05$).

Weeds of Green Acres Farm

Xanthium, Amaranthus and Bidens were the only weeds that germinated heavily after being artificially sowed. All weed communities were dominated by Richardia, although Xanthium and Bidens reached density values high enough to make treatments 2 and 3 different from each other and also from the natural weed complex (Table 5). Amaranthus germinated slowly and was part of the weed community in treatment 2. Cassia and grasses were not part of the natural background of weeds of the area. Populations of goldenrod, camphorweed, evening primrose, dandelion and mexican tea remained low during the study, but by the end of the corn's cycle their densities started to increase in the different plots.

Pest Incidence

As shown in Table 6, the percent of corn plants with whorls damaged by fall armyworm larvae was higher in the monocultures than in any of the weed diversified corn plots, at both localities. At Tall Timbers Research Station the incidence of fall armyworm was mostly reduced when growing corn in association with a highly fertilized natural weed complex. At Green Acres, fall armyworm incidence was reduced mostly when growing corn with a rye straw mulch. It is possible that a rye straw mulch may change the color or shape of the corn background thus affecting the colonization of fall armyworm which seems to respond to visual cues in locating a host (Southwood and Way 1970).

Fall armyworm incidence and weed density appeared to be inversely correlated at Tall Timbers ($r = -.93$). As the density of plants in the weed community increased, the percent of damaged whorls in the plots

Table 5. Relative abundance and species numbers of weed communities within corn fields at Gainesville, Florida (1979).

Treatment	Weed community	Mean % cover \pm std. deviation	Mean number of weed species
2	Weed mixture A (n=3)		
	<u>Xanthium</u>	35.0 \pm 0.0	5b*
	<u>Amaranthus</u>	11.6 \pm 3.8	
	<u>Richardia</u>	40.0 \pm 6.6	
3	Community	85.0b \pm 0.0	
	Weed mixture B (n=3)		
	<u>Bidens</u>	25.0 \pm 18.5	4b
	<u>Richardia</u>	66.6 \pm 18.3	
5	Community	90.0b \pm 3.3	
	Natural weed complex (n=3)		
	<u>Richardia</u>	62 \pm 20.3	2a
	Community	66.6a \pm 21.6	

* Means followed by the same letter, on any given column, are not significantly different according to Duncan's multiple range test ($p = 0.05$).

decreased (Fig. 1). This suggests that the fall armyworm regulatory mechanisms that emerge from growing weeds in corn fields are accentuated with an increase in the population density of desired weeds.

At both localities, incidence of corn earworm was similar among most treatments (Table 6). At Tall Timbers the lowest damage (non-significant) occurred in the weed treatment 2 and at Green Acres less damaged ears were observed where corn was grown with a strip of soybean. Based on these results, it seems that Heliothis responds very differently to habitat diversity than Spodoptera does. It is possible that these species have different habitat colonization strategies. Intercropping corn and soybean might be of aid in reducing corn earworm infestations.

In general, the magnitude of the incidence of both pest complexes varied according to the area. Fall armyworm attack was more severe at Tall Timbers, whereas the incidence of corn earworm was more severe at Green Acres. It should be noted, however, that damage evaluations were made in different years, and these trends may change from year to year.

Predator Colonization

At the early stages of crop development only a few predaceous arthropods colonized the corn fields. As food and habitat resources became more available, numbers of predators and species richness at each locality increased (Table 7). As the corn plants developed, environmental conditions in both localities were ameliorated with time. Weedy corn systems apparently became milder in microclimate and more complex in trophic and habitat structure than the monocultures. These changes affected the number and diversity of colonizing predator species.

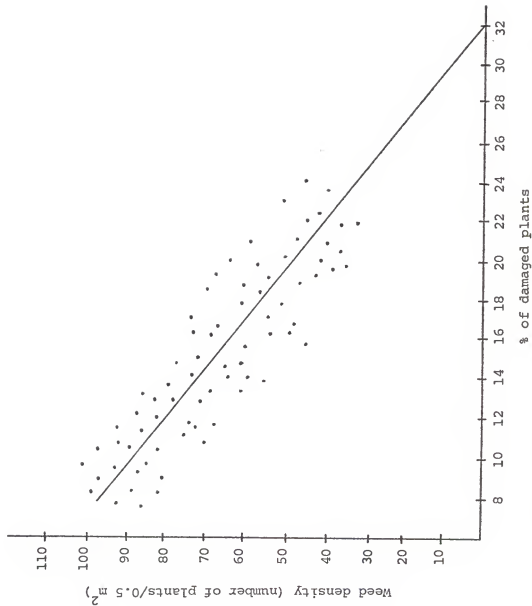


Figure 1. Relationship ($y = 104 - 0.2x$) between weed density and percent of corn plants damaged by fall armyworm (Spodoptera frugiperda J.E. Smith) in north Florida; $r = -0.93$, $n = 15$ /mean.

Table 6. Percent of damaged plants by fall armyworm, *Spodoptera frugiperda* J.E. Smith, and percent of ears damaged by corn earworm, *Heliothis zea* (Boddie), in weed-free and weed-diversified corn systems at two sites in north Florida.

Corn system	Tall Timbers Research Station (1978)		Green Acres Farm (1979)	
	fall armyworm (n=15)	corn earworm (n=9)	fall armyworm (n=15)	corn earworm (n=6)
Monoculture	31.5a* \pm 11.6**	32.7a \pm 26.6	15.1a \pm 7.9	65.0a \pm 9.4
Weed mixture A	12.9b \pm 10.2	28.3a \pm 20.3	7.3b \pm 3.6	56.6ab \pm 37.7
Weed mixture B	20.1b \pm 11.3	35.6a \pm 26.5	7.7b \pm 3.0	59.2a \pm 22.7
Natural weed complex	15.8b \pm 11.8	32.2a \pm 23.7	5.5b \pm 3.6	69.2a \pm 18.0
Natural weed complex highly fertilized	9.40c \pm 8.5	35.6a \pm 22.7	--	--
Natural weed complex determined by December plowing	19.5b \pm 11.8	38.3a \pm 22.2	--	--
Soybean strip	--	--	9.7b \pm 3.9	53.3b \pm 29.8
Rye straw mulch	--	--	1.3c \pm 0.9	60.5a \pm 35.0

* Means followed by the same letter, on any given column, are not significantly different according to Duncan's multiple range test ($p = 0.05$).

** Means \pm standard deviation.

Table 7. Colonization of corn systems by predaceous arthropods in north Florida. (Only dominant predaceous species are listed for each census at the two sites).

Site	Year	April	May	June	July	August
Corn Monoculture	Tall Timbers (70)	---	Doru, Leptotrachelus Coccinellidae, Dolichopodidae, Callida, Podisus, Peucebia	Doru, Coccinellidae Peucebia, Callida, Geocoris, Leptotrachelus	Doru, Coccinellidae Geocoris, spiders	Doru, Geocoris spiders, Dolichopodidae Reduviidae
	Green Acres (79)	Spiders, Coccinellidae	Spiders, Coccinellidae, Geocoris, Callida, Doru Orchelimum, Peucebia, Orius Heterosus	Geocoris, Heterosus, Orchelimum, Dolichopodidae, Spiders, Scymnus, Orchelimum	Doru, Spiders, Heterosus	-----
	Tall Timbers (78)	-----	Dolichopodidae, Coccinellidae, Doru, Spiders, Callida, Podisus, Tropiconabis	Spiders, Orchelimum Dolichopodidae, Coccinellidae, Doru, Callida, Podisus, Geocoris, Leptotrachelus	Doru, Geocoris, Coccinellidae, spiders, Dolichopodidae, Reduviidae	Spiders, Dolichopodidae Geocoris, Doru, Orchelimum
Corn and Natural Weed Complex	Green Acres (79)	Spiders, Coccinellidae, Peucebia	Coccinellidae, spiders Callida, Orchelimum, Coccinellidae, Peucebia, Geocoris, Leptotrachelus, Heterosus, Doru Orius	Heterosus, Orius, Doru, Peucebia, Geocoris, Iobia, Dolichopodidae, Scymnus Orchelimum, Orchelimum Spiders	Doru, Spiders, Geocoris, Scymnus	-----

Table 7 - continued

Site	Year	April	May	June	July	August
Corn and Selected Weed Associations	Tall Timbers (70)	-----	Psocetia, Podisus, Tetralonchus, Coccinellidae, Dolichopodidae, Spiders, Doru, Reduviidae Leptorachelus, Callida, Orchelimum Coccinellidae	Leptorachelus, Callida, Doru, Dolichopodidae, Coccinellidae, Podisus, Sinea Jassidea, Spiders, Orchelimum, Coccinellidae, Lebia Coccinellidae	Doru, Geocoris Leptorachelus, Coccinellidae, Spiders, Lebia, Sinea Dolichopodidae	Doru, Spiders Dolichopodidae Geocoris, Leptorachelus, Orchelimum, Coccinellidae Reduviidae
	Green Acres (79)	Spiders, Coccinellidae	Coccinellidae Doru, Psocetia, Tetralonchus, Spiders, Geocoris Oris, Notoxus, Callida	Notoxus, Psocetia Spiders, Geocoris Orchelimum, Doru, Coccinellidae, Oris, Dolichopodidae, Coccinellidae Desanthus, Orchelimum	Doru, Spiders, Geocoris, Coccinellidae, Orchelimum	-----

At Tall Timbers, corn grown intermingled with natural weed complexes and selected weed associations showed higher numbers of predator species per unit area (Table 8) and greater numbers of predators (Table 9) than monocultures. These trends were consistent throughout the growing season. Later, when the corn reached harvest maturity, predator numbers and diversity declined. Similar trends were observed by Price (1976) and Mayse and Price (1978) in soybean fields when analyzing croplands from the theory of island biogeography.

The above results suggest that predators in monocultures operate in a more xeric environment which influence their colonization and extinction rates dramatically. At Green Acres there were no differences in predator diversity among the various plots. Only in June the diversity of predator species was higher in the weed diversified systems than in the monocultures. Because the habitats surrounding the Tall Timbers plots were structurally more complex and probably provided more local overwintering sites for predators, the mean number of predators were higher there than in Green Acres. Species richness was similar at both sites, however. It seems that by growing corn plants intermingled with weeds or by retaining complex uncultivated borders around the fields, colonization rates of predators are accelerated and extinction rates are reduced (Price 1976).

Predator Abundance and Diversity

At Tall Timbers, predator abundance and diversity (number of species per unit area) on corn plants were significantly higher in weed-diversified systems than in weed-free systems. Arthropod complexity seemed to parallel the trend in plant complexity. Conversely,

Table 8. Mean number of predator species throughout the growing season in weed-free and weed-diversified corn systems at two sites in north Florida.

Corn system	Site	Year	Mean number of predator species					Total Mean \pm Std. deviation
			April	May	June	July	August	
Corn monoculture	Tall Timbers (n=36)	(78)	---	4.0	4.2	3.5	3.5	3.9a \pm 1.2*
	Green Acres (n=33)	(79)	1.3	3.8	5.3	3.0	---	3.4a \pm 1.5
Corn and natural weed complex	Tall Timbers (n=36)	(78)	---	5.0	4.4	6.0	4.5	4.9b \pm 1.2
	Green Acres (n=33)	(79)	0.5	3.3	7.0	3.0	---	3.5a \pm 1.9
Corn and selected weed associations	Tall Timbers (n=36)	(78)	---	4.3	4.5	4.6	4.3	4.2b \pm 0.9
	Green Acres (n=33)	(79)	0.8	3.9	6.5	3.5	---	3.6a \pm 1.9

* Mean in the same year, followed by the same letter, on any given column, are not significantly different according to Duncan's multiple range test ($p = 0.05$).

Table 9. Total numbers and diversity of general predators in different corn cropping systems at two sites in north Florida.

Corn system	Number of individuals and species of predators per 30 corn plants \pm std. deviation			
	Tall Timbers Research Station (1978)		Green Acres Farm (1979)	
	Abundance (n=36)	Diversity (n=36)	Abundance (n=33)	Diversity (n=33)
Monoculture	7.2a \pm 4.8	3.9a \pm 1.2	4.9a \pm 2.3	3.4a \pm 1.5
Selected weed associations	8.8b \pm 5.8	4.2b \pm 0.9	4.3ab \pm 2.9	3.6a \pm 1.9
Natural weed complex	8.6b \pm 4.8	4.9b \pm 1.1	3.7b \pm 1.6	3.5a \pm 1.8
Rye straw mulch	---	---	3.7b \pm 2.8	3.1a \pm 1.8
Soybean strip	---	---	4.0b \pm 2.2	3.7a \pm 1.5

* Mean followed by the same letter, on any given column, are not significantly different according to Duncan's multiple range test ($p = 0.05$).

at Green Acres total predator numbers on corn plants were slightly greater on the monocultures than on the diverse corn systems. There were no differences in the number of species of predators between weed-free and weed-diversified corn systems at Green Acres. If mean numbers of species and individuals per habitat space (predators on corn plus predators on weeds in each plot) are considered, population densities and species diversity or predators bypass significantly the levels reached by predators in the monocultures at Green Acres. A quantitative value of predators per habitat space cannot be given in the present study because predator populations were estimated by absolute methods in the corn plants and by a relative method on the weeds. The qualitative assumption that predators were more abundant and diverse in the weedy corn fields than in the monocultures seems valid because predators moved back and forth between the weeds and the corn (Fye 1972).

It is possible that the high numbers of predators in the Green Acres monocultures were due to the proximity of the experimental plots (8 m apart) which could not prevent migration of predators from diverse plots (Root 1973). This problem seemed to be minimized at the Tall Timbers experiments mainly because of the greater distance between plots.

In general, population densities of predators were greater in the Tall Timbers plots than in those at Green Acres. These differences were probably due to the nature of the surrounding habitats (Hodek 1973). Tall Timbers plots were surrounded by annually burned pinelands, complex early successional weedy fields and remanent tree forests which apparently served as refugia providing a continuous influx of predators.

The Green Acres plots were surrounded by sorghum and corn fields, weedy fields dominated by Linaria and Brassica and later by soybean fields. The temporary nature of these habitats and the heavy pesticide treatments that they go through make them poor predator reinforcement resources (Fuchs and Harding 1976). The presence of two extra weed rows in each plot at the Tall Timbers experiment might explain the differences in predator abundance between weedy plots at both localities. Those extra weed rows probably improved the habitat and resource base available for predators at Tall Timbers.

Trends of Individual Predator Species

Each predator species, family or both responded differently to the various treatments (Table 10). Population responses varied according to species involved, weed diversity, year and locality. For example, Geocoris spp. numbers were higher in weed-diversified systems (particularly the natural weed complex) than in corn monocultures at Tall Timbers in 1978, but Geocoris spp. showed no response to weed diversity at Green Acres in 1979. Corn associated with the natural weed complex had higher numbers of predaceous Coleoptera (Carabidae and Notoxus) than any other system at Green Acres and more predaceous Hemiptera (Nabidae, Orius and Zelus) and Coccinellidae than any other treatment at Tall Timbers. Doru sp. had similar densities in all treatments at Tall Timbers, but higher densities in the weed-free monocultures and corn-soybean systems than weed-diverse plots at Green Acres. Spider densities (including Peucetia viridans (Hentz)) were similar in all treatments at both sites. Predaceous Orthoptera (Orchelimum sp. and Oecanthus sp.) reached low densities in all treatments.

Table 10. Relative abundances of individual predator species in different corn cropping systems at two sites in north Florida. (Averages of 12 sampling dates).

Corn system	Site	Year	Doru sp.	Spiders	Numbers of individuals per 30 corn plants \pm std. deviation					
					Coccinellidae	Peucetia	Cecoris	Hemiptera	Coleoptera	Predaceous Orthoptera
Monoculture	Tall Timbers*	(78)	5.2a \pm 3.7**	0.2 a \pm 0.2	0.7 a \pm 0.45	0.10a \pm 0.13	0.15a \pm 0.13	0.07a \pm 0.1	0.1 a \pm 0.13	0.0 a \pm 0.0
	Green Acres***	(79)	1.9a \pm 1.6	0.6 a \pm 0.4	0.34a \pm 0.15	0.47a \pm 0.56	0.50a \pm 0.5	0.5 a \pm 0.9	0.3 a \pm 0.2	0.08a \pm 0.1
Selected weed associations	Tall Timbers	(78)	5.6a \pm 3.2	0.32a \pm 0.23	0.90a \pm 0.5	0.05a \pm 0.05	0.35a \pm 0.25	0.1 a \pm 0.1	0.24a \pm 0.2	0.05b \pm 0.04
	Green Acres	(79)	0.8b \pm 0.5	0.4 a \pm 0.2	0.4 a \pm 0.2	0.50a \pm 0.4	0.53a \pm 0.4	0.51a \pm 0.2	0.34a \pm 0.2	0.01a \pm 0.01
Natural weed complex	Tall Timbers	(78)	4.7a \pm 2.8	0.2 a \pm 0.15	1.5 b \pm 1.0	0.0 b \pm 0.0	0.69b \pm 0.8	0.13a \pm 0.15	0.15a \pm 0.13	0.03b \pm 0.01
	Green Acres	(79)	0.6b \pm 0.6	0.4 a \pm 0.2	0.3 a \pm 0.15	0.50a \pm 0.4	0.47a \pm 0.4	0.27a \pm 0.4	0.70b \pm 0.5	0.05a \pm 0.06
Soybean strip	Tall Timbers	(78)	---	---	---	---	---	---	---	---
	Green Acres	(79)	1.7b \pm 0.9	0.15a \pm 0.1	0.26a \pm 0.1	0.60a \pm 0.04	0.67a \pm 0.4	0.41a \pm 0.5	0.23a \pm 0.15	0.02a \pm 0.01
Rye straw mulch	Tall Timbers	(78)	---	---	---	---	---	---	---	---
	Green Acres	(79)	0.9b \pm 0.6	0.2 a \pm 0.1	0.11a \pm 0.1	0.50a \pm 0.3	0.39a \pm 0.1	0.99b \pm 0.0	0.47a \pm 0.2	0.15b \pm 0.09

* n=36

** Means in a same year, followed by the same letter, on any given column, are not significantly different according to Duncan's multiple range test ($p = 0.05$).

*** n=33

Predation Pressure

Table 11, shows the mean percent of Spodoptera eggs consumed by predators at both localities. There seemed to be no relationship between predator abundance, weed diversity and predation pressure. Rather, the percent of eggs consumed by predators was greater or equal to some weedy treatments in the monocultures of Tall Timbers at all sampling dates. At Green Acres predators consumed more eggs in the monocultures and in the corn-soybean strip system than in any other weed-diverse system. These results would imply that predators are more efficient in consuming eggs in the monocultures. However, it seems that eggs are more easily found by predators in monocultures. The lack of other natural prey and the simplicity of the environment in a monoculture facilitates the search of artificially placed eggs by the few predators present. Conversely, in weed diversified systems physical and trophic structures are more complex somehow diverting the attention of predators from the eggs. In cereal fields of England, Speight and Lawton (1976) found contrasting trends. The number of pupae taken by predators increased with the density and frequency of weeds. Habitat diversity provides adequate microclimates and enough food for predators forcing them to slow down and remain longer in the complex habitat (Root 1973). Predators never consumed less than 50% of the placed eggs in the complex environments. The question remains whether this rate of consumption would actually prevent an outbreak of fall army-worm.

At Green Acres, the highest consumption of eggs occurred in the monoculture and in the soybean strip corn systems. Because of the

Table 11. Mean percent of Spodoptera eggs consumed by predators over four sampling dates at two sites in north Florida.

Corn system	Mean % of eggs consumed \pm std. deviation	
	Tall Timbers Research Station, 1978 (n=24)	Green Acres Farm, 1979 (n=18)
Monoculture	79.2a \pm 21.2	71.9a \pm 2.7
Weed mixture A	67.5b \pm 19.9	44.1c \pm 25.0
Weed mixture B	73.9a \pm 19.7	53.1b \pm 25.5
Natural weed complex	80.1a \pm 15.4	46.3bc \pm 15.1
Natural weed complex highly fertilized	64.8b \pm 18.9	---
Natural weed complex determined by December plowing	68.7b \pm 20.9	---
Soybean strip	---	70.1a \pm 3.5
Rye straw mulch	---	55.3b \pm 11.1

* Means followed by the same letter, on any given column, are not significantly different according to Duncan's multiple range test ($p = 0.05$).

proximity of the plots, it seems obvious to assume that predators were moving from the diverse plots to rapidly consume the more "apparent" eggs placed in the monocultures.

The high variance associated with the egg predation data probably reflects the element of chance involved in the predators locating and taking the prey offered to them in the small, discrete groups presented by individual paper quadrats.

Predators actually observed taking eggs in the field included Doru sp., Orchelimum sp., Peucetia viridans (Hentz), Hippodamia convergens (Guerin-Men), Coleomegilla maculata DeGeer, Orius insidiosus Say, Leptotrachelus dorsalis (Fab.), Callida decora (Fab.), various spiders and ants.

Weeds and Number of Ground Predators

In Table 12, the data on the adult ground predator fauna (spiders, earwigs, beetles and ants) caught in the set of pitfall traps over the four sampling dates at both sites are summarized. Although pitfall sampling has been criticized as a technique which poorly estimates total numbers and may sample with varying effectiveness in different habitats (Luff 1975), in this study pitfalls were considered a useful method to obtain a relative estimate of the presence of ground predators in the different plots.

Spider numbers were greater in the monocultures and in the corn systems with weed mixture B at Green Acres. Earwigs were more actively present in the corn systems with a rye straw mulch and monocultures than in the corn systems with weeds and soybean. Figure 2 shows some abundance trends of earwigs in the mulched and monoculture systems at

Table 12. Mean numbers of ground predators caught by pitfall traps in different corn cropping systems at two sites in north Florida (Average of four sampling dates).

Corn system	Mean numbers of predators \pm std. deviation			
	Tall Timbers Research Station, 1978		Green Acres Farm, 1979	
	carabids (n=12)	ants (n=12)	<i>Labidura riparia</i> Pallas (earwig) (n=24)	Spiders (n=24)
Monoculture	3.2a \pm 1.5	9.8b \pm 1.8	18.5b \pm 4.9	8.4a \pm 4.4
Weed mixture A	3.4a \pm 2.5	6.9c \pm 4.2	14.0bc \pm 2.4	6.1b \pm 2.7
Weed mixture B	1.6b \pm 1.3	8.6b \pm 1.4	11.9c \pm 1.4	7.6a \pm 3.8
Natural weed complex	3.0a \pm 1.3	11.0a \pm 1.6	11.4c \pm 2.3	5.4b \pm 1.6
Natural weed complex highly fertilized	2.3a \pm 2.2	9.1b \pm 3.8	---	---
Natural weed complex determined by December plowing	1.4b \pm 1.4	5.6c \pm 1.8	---	---
Soybean strip	---	---	13.1c \pm 1.5	6.2b \pm 2.7
Rye straw mulch	---	---	23.5a \pm 9.5	2.6c \pm 1.3

* Means followed by the same letter, on any given column, are not significantly different according to Duncan's multiple range test ($p = 0.05$).

Green Acres during the four sampling dates. Earwigs were more abundant in the mulched plots. There is evidence which suggests that earwigs are favored by soil covers and other similar cultural manipulations (van den Bosch and Telford 1964). These evidences would imply that earwigs reproduced in the mulched systems and later dispersed to the other plots. During the second and third sampling dates earwig numbers were similar in the mulched plots and monocultures. Possibly, they concentrated more in the monocultures than in the weedy plots because they did not find resistance to movement throughout the plots otherwise imposed by the dense vegetation strips in the weedy plots. At the last sampling date earwig populations were again higher in the mulched plots than in the monoculture. Pitfall trapping apparently extracts great part of the reproductive adult earwig population in the mulched plots. If these plots are not sampled for a certain period of time (12 days), earwig populations recover their original levels in the mulch treatments bypassing in abundance the earwigs of the monocultures (Fig. 2).

At Tall Timbers carabids presented similar abundance levels in the monocultures and three weed-diversified corn systems. Ants were significantly more abundant in the corn system with the natural weed complex. There were no differences in the abundance of ants between the monocultures and two weed-diversified plots.

Predator Dynamics in Weed Habitats

Several studies have shown that predator numbers and diversity increase when the complexity of the plant community is enriched (Root 1973). In cereal fields of England, Speight and Lawton (1976) found

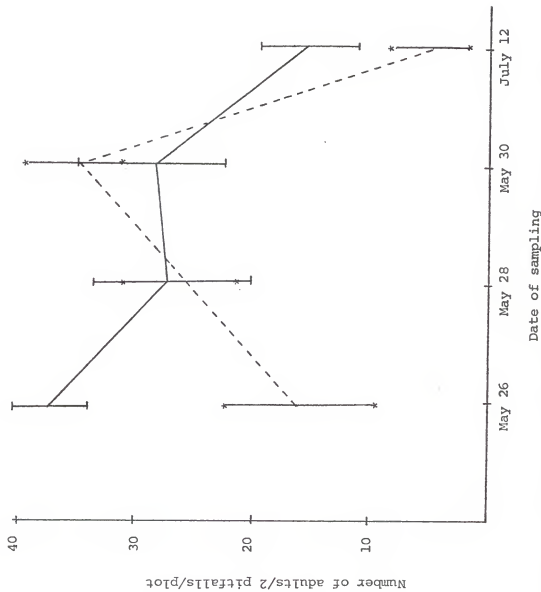


Figure 2. Comparison of mean abundance of *Labidura riparia* (Pallas) in mulched corn plots (solid line) and bare soil corn plots (dotted line) in north Florida; confidence limits ($\alpha = 0.05$) indicated for each mean.

that the total number of ground beetles caught per pitfall traps increased as a function of the density of weeds. Other researchers have compared the predator fauna of croplands and fallow fields (Allan et al. 1975) but no attempts have been made to compare the predator fauna associated with different weed communities within crop fields.

The present study shows that through different manipulations (direct sowing, differential fertilization, early plowing, etc.) different weed communities can be established in corn fields. These communities sustain predator complexes of various species diversities and relative abundances (Table 13). Furthermore, because the predators on the weeds move back and forth between the corn and weeds, the predator species present on the corn also change. At Tall Timbers, weed communities determined by December plowing, high fertilization (872 kg/ha) and direct sowing of mixture A presented the highest densities of predators. The predator fauna was significantly more diverse in the highly fertilized weed community than in any other weed community. Figure 3 suggests a direct relationship ($r = .96$) between the number of weed species and the abundance of predators in the weed communities at Tall Timbers.

Results from the Green Acres Farm show that relative abundances of predators are similar between certain weed communities and also between weed communities and the soybean strip. Also, there were no significant differences in species richness among the various weed communities and soybean strip. It should be noted that these trends might be masked because of the proximity of the plots.

Total mean number of predators and number of species associated with the different weed communities were significantly greater

Table 13. Mean relative density and number of species of predators associated with weed communities within corn fields at two sites in north Florida.

Weed community	Density and number of predator species \pm std. deviation			
	Tall Timbers Research Station, 1978*		Green Acres Farm, 1979**	
	Density (n=36)	Number of species (n=36)	Density (n=21)	Number of species (n=21)
Weed mixture A	9.3ab*** \pm 2.8	5.8b \pm 0.73	4.3a \pm 0.8	3.8a \pm 1.1
Weed mixture B	7.6b \pm 2.0	6.1b \pm 0.86	4.4a \pm 0.6	4.6b \pm 0.53
Natural weed complex	7.9b \pm 2.1	5.6b \pm 0.93	3.6a \pm 1.0	4.3ab \pm 1.2
Natural weed complex highly fertilized	8.9ab \pm 2.5	6.6a \pm 0.86	---	---
Natural weed complex determined by December plowing	10.3a \pm 2.8	5.2c \pm 1.1	---	---
Soybean strip	---	---	4.1a \pm 1.2	4.1ab \pm 1.1
Mean total	8.8	5.8	4.1	4.2

* Average of 12 sampling dates. Numbers per 20 net sweeps per 10 m² of weeds.

** Average of 7 sampling dates. Numbers per 20 net sweeps per 10 m² of weeds.

*** Means followed by the same letter, on any given column, are not significantly different according to Duncan's multiple range test ($p = 0.05$).

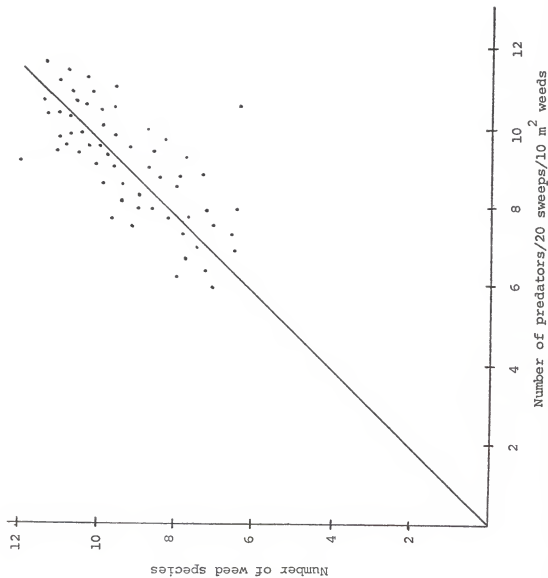


Figure 3. Relationship ($y = 0 + 0.58x$) between weed species diversity and predator abundance in weed communities of north Florida corn fields; $r = 0.84$, $n = 12/\text{mean}$.

(Table 13) at Tall Timbers than at Green Acres. The structurally more complex habitat surrounding the Tall Timbers plots possibly accounted for these differences.

The mean numbers of individual predator species and families collected on the different weed communities at both sites are summarized in Table 14. In general most predators reached similar densities in all communities. At Tall Timbers, Doru sp. was particularly abundant in the weed mixture A community and predaceous Orthoptera (Orchelimum sp. and Oecanthus sp.) reached the lowest densities in the natural weed complexes. Coccinellidae were somewhat more abundant in the highly fertilized weed complexes. Doru sp. was the only predator species which was slightly more abundant in the soybean strip than on the weed communities of Green Acres.

Crop Yields

The purpose of this study was to establish principles of corn pest management under different ecological conditions and not to develop methods to enhance crop production. Crop yields were measured, however, in order to have a basis to evaluate the agronomic potential of the proposed systems.

The mean corn yields of the different cropping systems at both localities are shown in Table 15. In general, corn yields were lower at Tall Timbers (mean for all treatments = 2.15 tons/ha) than yields at Green Acres (mean for all treatments = 3.28 tons/ha) probably because of a severe drought that affected Tallahassee during the 1978 summer. Both mean yield values do not fall under the average corn yields of farmers in USA during 1970 (2.057 tons/ha) reported by

Table 14. Mean numbers of individual predator species and families collected on weed communities within corn fields at two sites in north Florida.

Weed community	Site	Year	Number of individuals per 20 net sweeps on 10 m ² of weeds \pm std. deviation									
			Doru sp.	Spiders	Coccinellidae	Pentatonia	Coccinella	Hemiptera	Coleoptera	Predaceous Orthoptera		
Weed mixture A	Tall Timbers*	(78)	2.0 \pm 1.3**	1.4 \pm 0.7	0.3 \pm 0.3	1.3 \pm 0.84	0.1 \pm 0.13	0.6 \pm 0.4	0.3 \pm 0.1	1.9 \pm 0.9		
	Green Acres***	(79)	0.1 \pm 0.15	0.9 \pm 0.5	0.04 \pm 0.02	1.1 \pm 0.48	0.8 \pm 0.56	0.2 \pm 0.1	0.5 \pm 0.3	0.3 \pm 0.17		
Weed mixture B	Tall Timbers	(78)	1.3 \pm 0.8	1.3 \pm 0.7	0.4 \pm 0.3	0.9 \pm 0.7	0.2 \pm 0.1	0.6 \pm 0.4	0.5 \pm 0.2	1.4 \pm 1.1		
	Green Acres	(79)	0.08 \pm 0.07	0.5 \pm 0.3	0.2 \pm 0.15	0.7 \pm 0.4	1.1 \pm 0.8	0.4 \pm 0.2	0.4 \pm 0.15	0.3 \pm 0.1		
Natural weed complex	Tall Timbers	(78)	1.0 \pm 0.7	1.4 \pm 0.8	0.5 \pm 0.3	0.9 \pm 0.3	0.5 \pm 0.4	0.4 \pm 0.3	0.5 \pm 0.2	0.6 \pm 0.2		
	Green Acres	(79)	0.3 \pm 0.1	0.6 \pm 0.2	0.1 \pm 0.05	0.9 \pm 0.6	0.6 \pm 0.3	0.2 \pm 0.15	0.4 \pm 0.1	0.4 \pm 0.3		
Natural weed complex highly fertilized	Tall Timbers	(78)	1.0 \pm 0.6	1.3 \pm 0.8	0.9 \pm 0.8	1.5 \pm 0.9	0.4 \pm 0.2	1.0 \pm 0.8	0.5 \pm 0.2	1.4 \pm 0.8		
	Green Acres	(79)	---	---	---	---	---	---	---	---		
Natural weed complex determined by December plowing	Tall Timbers	(78)	1.6 \pm 1.1	0.9 \pm 0.6	0.1 \pm 0.08	0.6 \pm 0.2	0.3 \pm 0.2	0.5 \pm 0.3	0.4 \pm 0.1	0.2 \pm 0.1		
	Green Acres	(79)	---	---	---	---	---	---	---	---		
Soybean Strip	Tall Timbers	(78)	---	---	---	---	---	---	---	---		
	Green Acres	(79)	0.4 \pm 0.1	0.3 \pm 0.1	0.2 \pm 0.1	0.9 \pm 0.3	0.9 \pm 0.4	0.1 \pm 0.05	0.4 \pm 0.3	0.3 \pm 0.05		

* Average of 12 sampling dates (n=36).

** Means in a same year, followed by the same letter, on any given column, are not significantly different according to Duncan's multiple range test (p = 0.05).

*** Average of 7 sampling dates (n=21).

Table 15. Average corn yields under different cropping systems at two sites in north Florida.

Corn systems	Tons per hectare \pm std. deviation	
	Tall Timbers Research Station, 1978 (n=3)	Green Acres Farm, 1979 (n=3)
Monoculture	2.88a \pm 1.38	4.86a \pm 0.38
Weed mixture A	3.46a \pm 1.2	3.36b \pm 0.32
Weed mixture B	2.00b \pm 0.85	3.22b \pm 0.7
Natural weed complex	1.32c \pm 0.04	2.84b \pm 0.6
Natural weed complex highly fertilized	2.36b \pm 1.34	---
Natural weed complex determined by December plowing	0.93c \pm 0.68	---
Soybean strip	---	4.03a \pm 0.63
Rye straw mulch	---	1.37c \pm 0.2

* Means followed by the same letter, on any given column, are not significantly different according to Duncan's multiple range test ($p = 0.05$).

Pimentel et al. (1973). Considering the low energy inputs (no pesticides or irrigation) invested in the management of the plots, most yields seem economically and energetically acceptable.

Variances associated with yield means of some treatments were high at both localities (especially treatments 1, 2 and 5 at Tall Timbers and 3, 4 and 5 at Green Acres). In many cases this was due apparently to gradients in moisture or nutrient levels in the soil. In a few instances low yields in a replicate resulted from patchiness in the attack of soil nematodes.

At Tall Timbers, corn monocultures and corn-weed mixture A systems presented similar yields. All other treatments showed lower yields. The lowest yields at Tall Timbers were observed in the corn systems associated with the natural weed complex and with the natural vegetation resulting from an earlier December plowing. The latter system was more mature than any of the other weed treatments and had a background of perennials (e.g., Rubus sp., Phytolaca sp.), aggressive semi-annuals (Crotalaria sp., Eupatorium sp., Ipomoea sp.) and grasses which tended to invade the corn rows on a regular basis. At Green Acres, corn monocultures and corn-soybean strip systems showed the highest yields. All other corn-weed associations had lower yields. The lowest yields were observed in the corn systems with a rye straw mulch. There are certain evidences which suggest that rye residues might exert allelopathic effects on certain plants, including corn (Rice 1974).

Although the selective presence of weeds within corn plots reduces the incidence of fall armyworm, this reduction is unacceptable from the yield point of view. This suggests that any advantage

offered by weeds to establish a pest equilibrium in corn fields is to some extent offset by their interference (competition/allelopathy) with crops, even if weeds are grown as alternate rows. A direct and intense interference between weeds and crops grown in separate rows is unlikely and has not been reported in the literature. Also, there remains the question that no matter how much weeds reduce the incidence of fall armyworm in corn, because corn can tolerate sizeable populations of Spodoptera (Beingolea 1957) without yields being affected. Thus, differences in yields between weed-free corn plots and corn systems diversified with strips of weeds are explained by other factors not considered in the present study.

CONCLUSIONS

Present research suggests that it is possible to design corn agro-ecosystems to reduce the incidence of fall armyworm, Spodoptera frugiperda. By proper cultural manipulations (e.g., direct sowing, differential soil fertilization, early plowing, etc.) certain weed communities can be established within corn fields. The presence of these weed associations addstrophic and structural diversity to the corn systems which result in two main effects:

1. Act as plant defense guilds (Atsatt and O'Dowd 1976) with anti-herbivore properties, reducing the incidence of Spodoptera frugiperda. The biotic, structural, chemical and microclimatic complexity of corn-weed mixed systems greatly ameliorates the noctuid pressure early in the growing season. At Green Acres, Spodoptera damage was reduced most when corn was grown in association with the natural weed complex. At Tall Timbers, fall armyworm damage decreased as the density of the weed community increased. Corn plants associated with a highly fertilized natural weed complex were least damaged by fall armyworm. It is possible that corn and natural weed complexes share coevolutionary links that enhance the associational resistance of the crop community (Root 1973, Murdoch 1975). It should be noted, however, that reduction of the incidence of fall armyworm might prove unacceptable from the yield point of view if weed interference is not effectively minimized.

2. Condition a continuously present set of natural enemies in the fields. At Tall Timbers, foliage predator arthropod communities were

more diverse and abundant in weedy plots than in weed-free plots. At Green Acres, predators were more abundant in the monocultures than in the weed-diversified systems, and predator diversity was equal in all treatment plots. An increase in the quantity of weeds in a given habitat space generally was correlated, both with an increase in the abundance and diversity of predaceous arthropods but not with an increase in the disappearance of artificial prey.

Heliothis zea (Boddie) was not affected by weed diversity. Only the diversification of corn systems with a strip of soybean decreased the number of ears damaged by corn earworm, suggesting that successful management of the corn earworm depends on introducing a select kind of diversity (e.g., corn-soybean polycultures), rather than general habitat diversity.

Results from crop-weed-insect predator interaction studies under experimental field conditions are dictated by a number of factors such as year, area, weed abundance and diversity, crop variety, etc., but more so by the distance between experimental plots.

A complication in designing experiments with plots close to each other is that the proximity of treatments permits insect predators to move easily from one habitat to other. Such movements constitute conservative errors tending to make predator fauna in the various treatments similar. For this reason, the diversity of the predator fauna was similar in all Green Acres plots and the densities of predators in the monocultures was higher or equal than those in some weed-diversified corn systems. A better approach to establish differences in predator levels between simple and diverse crop habitats is the design of well distanced experimental plots to prevent intercrop movements (like the Tall Timbers

experiments) or otherwise increase the size of the plots considerably. At Tall Timbers predators were clearly more abundant and diverse in the weedy corn plots than in the weed-free plots.

The data also suggest that the nature of the adjacent surrounding habitats can dramatically influence predator complexes within corn fields. Predator abundance and diversity were greater in corn plots surrounded by mature, complex, natural vegetation (e.g., annually burned pinelands at Tall Timbers Research Station) than when surrounded by simple, annual crop fields. Encouraging plant diversity within and outside corn fields increases the colonization rates of predators early in the season and decreases extinction rates by providing shelter and cover throughout the crop growth (Price 1976). It is tempting to extrapolate these results to a between-field comparison and suggest that corn fields adjacent to simple habitats will have fewer predators than fields with complex borders, with the result that outbreaks of fall armyworm are more likely in corn fields located in simple habitats. The long series of assumptions cast the validity of this argument because between field comparisons (like in this study) involve other factors such as location, size of the fields, year, corn varieties, etc., which may markedly influence pest and natural enemies dynamics.

Reduction of fall armyworm damage in corn grown with a rye straw mulch and in corn grown in concert with a soybean strip suggests the potential of both minimum tillage systems and intercropping systems of corn and soybean as possible strategies to complement management of this pest.

Elements of natural pest control undoubtedly exist in many mixed cropping systems (e.g., corn-weed associations) and there are certain

ways in which these may be transferred into agronomically convenient and economically acceptable monocultures. Based on these data corn systems surrounded by a complex habitat, mulched with some cereal straw and with a row of natural weeds between each 10 rows of corn might effectively prevent outbreaks of Spodoptera. Many of these systems will probably remain untried in the U.S. because of the potential for reduced production or lower profits. Given economic and energetic constraints and also due to the ecological impact of modern agricultural practices (e.g., pesticide pollution), agroecological strategies will have to be carefully evaluated on an environmental cost/benefit basis as well as on an energetic basis. The challenge for pest managers will be the design of a gentle technology which will be self operating with minimum external inputs. Capitalizing on knowledge of beneficial plant associations will provide a sound ecological basis to develop such technology.

APPENDIX

Table 16. Common predaceous arthropods of north Florida corn fields*.

	Collection sites	
	Tall Timbers Research Station, 1978	Green Acres Farm, 1979
COLEOPTERA		
Anthicidae		
<u>Notoxus monodon</u> Fab.	X	X
<u>Anthicus ephippium</u> Laf.	X	
Cantharidae		
<u>Chauliognathus</u> sp.	X	
<u>Podabrus</u> sp.	X	
Carabidae		
<u>Callida decora</u> (Fab.)	X	X
<u>Callida punctulata</u> Le Conte	X	
<u>Casnomia pennsylvanica</u> (L.)	X	
<u>Harpalus pennsylvanicus</u> DeGeer	X	
<u>Lebia analis</u> Dejean	X	
<u>Lebia viridis</u> Say	X	X
<u>Leptotrachelus dorsalis</u> (Fab.)	X	X
<u>Nemotarsus elegans</u> LeConte	X	X
<u>Pasimachus sublaevis</u> Beavois	X	
<u>Searites subterraneus</u> Fab.	X	
<u>Selenophorus palliatus</u> Fab.	X	
Coccinellidae		
<u>Coleomegilla maculata</u> DeGeer	X	X
<u>Cycloneda sanguinea</u> (L.)	X	X
<u>Exochomus marginipennis</u> Lec.	X	
<u>Hippodamia convergens</u> (Guerin-Men.)	X	X
<u>Hyperaspis</u> sp.	X	X
<u>Olla abdominalis</u> (Say)	X	X
<u>Scymnus</u> sp.	X	X
Malachiidae		
<u>Collops quadrimaculatus</u> (Fab.)	X	
Mordellidae		
<u>Mordellistena</u> sp.	X	X
<u>Mordella</u> sp.	X	X
Staphylinidae		
<u>Philonthus</u> sp.	X	X
<u>Pinophilus</u> sp.	X	X
DIPTERA		
Dolichopodidae		
<u>Condyllostylus caudatus</u> (Wied.)	X	X
<u>C. siphon</u> (Say)	X	X
<u>Mesorhaga albiciliata</u> (Aldrich)	X	

Table 16—continued.

Syrphidae			
	<u>Toxomerus floralis</u> (Fab.)	X	
	<u>T. marginatus</u> (Say)	X	
	<u>T. politus</u> (Say)	X	
DERMAPTERA			
Forficulidae			
	<u>Doru taeniatum</u> (Dohrn)	X	X
Labiduridae			
	<u>Labidura riparia</u> (Pallas)		X
HEMIPTERA			
Anthocoridae			
	<u>Orius insidiosus</u> Say	X	X
Lygaeidae			
	<u>Geocoris punctipes</u> (Say)	X	X
	<u>G. uliginosus</u> (Say)	X	X
Nabidae			
	<u>Nabis roscipennis</u> Reuter	X	X
	<u>Tropiconabis capsiformis</u> Germar	X	X
Pentatomidae			
	<u>Euthyrhynchus floridanus</u> (L.)	X	X
	<u>Podisus maculiventris</u> (Say)	X	
Reduviidae			
	<u>Atrachelus cinereus</u> (F.)	X	
	<u>Repipta taurus</u> (F.)	X	
	<u>Sinea</u> sp.	X	X
	<u>Sinea sanguisuga</u> Stal.	X	X
	<u>Zelus cervicalis</u> (Stal.)	X	X
HYMENOPTERA			
Formicidae			
	<u>Pheidole morrisi</u> Forel	X	
	<u>Pheidole</u> sp.	X	X
	<u>Conomyrma flavopecta</u> (Smith)	X	X
	<u>Solenopsis invicta</u> Buren	X	X
Sphecidae			
	<u>Spheg</u> sp.	X	
	<u>Tachytes</u> sp.	X	
Vespidae			
	<u>Polistes fuscatus</u> (Fab.)	X	
	<u>P. annularis</u> (Linn.)	X	X
NEUROPTERA			
Chrysopidae			
	<u>Chrysopa</u> sp.	X	X

Table 16—continued.

Hemerobiidae		
<u>Micromus posticus</u> (Walker)	X	
ORTHOPTERA		
Gryllidae		
<u>Oecanthus</u> sp.	X	X
Tettigoniidae		
<u>Orchelimum</u> sp.	X	X
ARANEAE		
Araneidae		
<u>Araneus juniperi</u> (Emerton)		X
<u>Eriophora ravilla</u> (Koch)		
<u>Tetragnatha laboriosa</u> Hentz	X	X
Anyphaenidae		
<u>Aysa</u> sp.	X	X
Clubionidae		
<u>Chiracanthium inclusum</u> (Hentz)	X	X
<u>Clubiona</u> sp.	X	X
Lycosidae		
<u>Pardosa georgiae</u> Chamberlin and Ivie	X	X
<u>Pardosa milvina</u> (Hentz)	X	X
<u>Lycosa</u> sp.	X	X
Oxyopidae		
<u>Oxyopes salticus</u> Hentz	X	X
<u>Peucetia viridans</u> (Hentz)	X	X
Philodromidae		
<u>Philodromus placidus</u> Banks		X
Salticidae		
<u>Hentzia palmarum</u> (Hentz)	X	X
<u>Phiddippus regius</u> (Koch)	X	X
<u>Methaphiddippus galathea</u> (Walck.)	X	X
Theridiidae		
<u>Latrodectus mactans</u> (Fab.)	X	X
<u>Theridion</u> sp.	X	X
Thomisidae		
<u>Misumenops</u> sp.	X	X
<u>Xysticus fraternus</u> Banks		X
<u>Xysticus texanus</u> Banks		X

* All specimens listed in this table were identified by Drs. R.E. Woodruff (Coleoptera), F. Mead (Homoptera, Hemiptera), H. Weems (Diptera) and G.B. Edwards (Araneae).

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Miguel A. Altieri was born in Santiago, Chile, on 3 September, 1950. He received his high school certificate in 1967 from the Liceo Experimental Manuel de Salas in Santiago. He also did his Junior Grade at the Notre Dame High School in Los Angeles, California, in 1966. Later, he received from the University of Chile his Bachelor of Science in Agronomy in May of 1974.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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